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VEGETATION & AIR QUALITY

ASSESSMENT OF POSSIBLE VEGETATION EFFECTS OF AIRBORNE EMISSIONS FROM THE BURRARD THERMAL GENERATING PLANT OPERATING ON NATURAL GAS

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Assessment of Possible Vegetation Effects of Airborne Emissions from the Burrard Thermal Generating Plant (BTGP) Operating on Natural Gas Fuel

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1.0 PREAMBLE

The present report was prepared under the following terms of reference:

Review possible air pollution symptoms observed on vegetation in the vicinity of the Burrard Thermal Generating Plant (BTGP) and define their probable cause;

Review existing data and studies of the possible occurrence of air pollution effects on vegetation in the Greater Vancouver Regional airshed;

Evaluate the probability of incremental emissions of BTGP being of a magnitude so as to affect plant growth or development;

Describe a reasonable monitoring programme to provide advanced warning of any possible effect on vegetation from future BTGP operations.

The report concerns the possible effects on local vegetation of emissions from the 600 MW operation of the BTGP, using natural gas fuel. Airborne emissions from the six 48.5 m-high stacks include quantities of the potentially phytotoxic gases nitric oxide, NO, and nitrogen dioxide, NO_2, (1). NO and NO_2 concentrations together are referred to as "oxides of nitrogen" (NO_x). Progressive oxidations in the atmosphere result in the conversion of NO to NO_2, the concentrations of both being influenced by dispersal of the plume (2).

The BGTP is located on the north shore of the eastern end of Burrard Inlet (Figure 1). High ground to the WNW rises to 290 m elevation within 2 km. To the NE, the ground rises to a plateau at 180 m at 3 km, and beyond climbs to over 1000 m at 7 km. To the SW, across Burrard Inlet, Burnaby Mountain rises to 350 m at 3 km. The land to S and SW forms a plateau at 160 m. BTGP thus lies in a topographic "bowl" created by this high ground; low land extending eastward from the eastern end of Burrard Inlet and the inlet itself to the west constitute gaps in the sides of the bowl. The

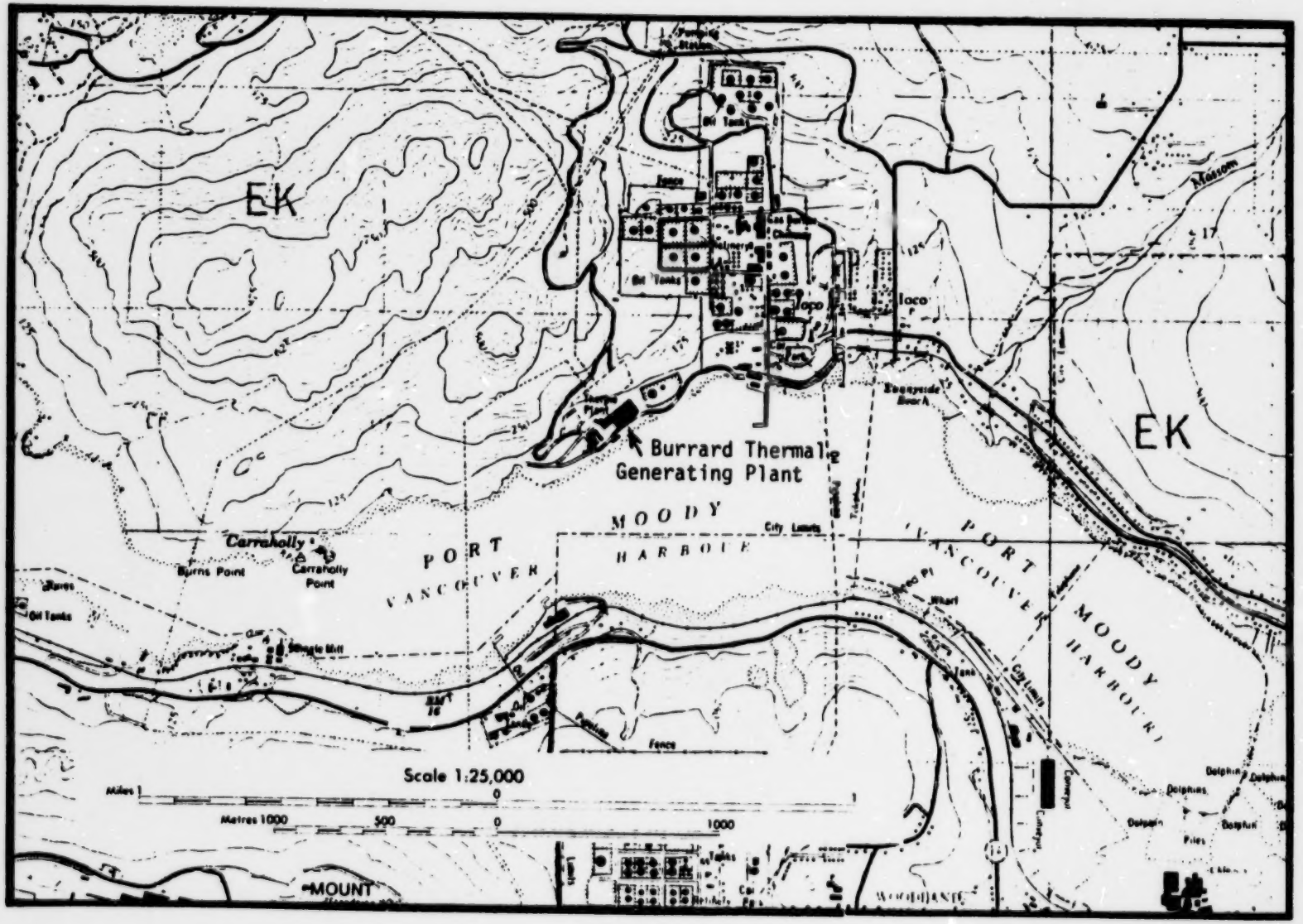


Figure 1. Map of eastern Burrard Inlet

topography dictates to some extent the nature and distribution of the vegetation present in the area.

Several other industries are located within the bowl, notably the Imperial Oil and Gulf Canada refineries, and further to the west, the Shell Canada oil refinery, all of which contribute NO_x and other emissions to the airshed.

The local meteorology is dictated by topography and synoptic conditions, in which several types of conditions have been identified (1) as being able to result in poor dispersion of the emissions, viz. fall stagnation episodes; arctic air outbreaks in winter leading to persistent easterly winds and temperature inversions; morning fumigation episodes; and land/sea breezes. The relevance of these conditions to NO_x dispersion and ambient concentrations has been investigated by means of releases of the tracer gas, sulphur hexafluoride (SF_6), in connection with plume dispersal studies and computer simulation modeling of BTGP emissions (1). These investigations indicate that 600 MW operation of BTGP would contribute NO_x to the airshed, and, under certain circumstances, could result in ambient concentrations close to 400 $\mu g\ NO_2/m^3$ (the maximum acceptable 1-hour Canada Air Quality objective), although much of the NO_2 could be attributable to sources other than BTGP.

The assessment of the likelihood and magnitude of any impact of BTGP emissions on local vegetation requires estimation of the probable responses of vegetation to the dosages represented by the estimated ambient concentrations and durations. The probable responses are, in turn, functions of the particular species present, the environmental factors which influence their susceptibility, and the interactive effects with other air pollutants present in the ambient air.

This report summarizes the available information on plant responses to NO_x (most data concern NO_2), alone and in the presence of other air pollutants. It indicates the types of extrapolations and the assumptions made in reaching an assessment of the probable impact on vegetation of the addition of BTGP emissions (operating at 600 MW) to NO_x from other sources. It concludes with a description of a general vegetation monitoring programme for the effects of NO_x in the region but which cannot attribute effects directly to BTGP.

2.0 SUMMARY AND RECOMMENDATONS

Information on the present ambient air quality in the region surrounding the eastern end of Burrard Inlet, together with estimates of air quality to be expected with 600 MW operation of the Burrard Thermal Generating Plant (BTGP), has been interrelated with the known effects on plants of the principal air pollutants emitted by BTGP, nitrogen dioxide (NO_2) and nitric oxide (NO), and their interactions with sulphur dioxide (SO_2) and ozone.

Information as to the sensitivity of indigenous species to the air pollutants in question is either sparse or non-existent. Hence, judgment has had to be used in assessing the impact, taking into account the numerous factors which influence plant susceptibility.

While BTGP's emissions at 600 MW will inevitably contribute to the total burden of NO_2 and NO in the region, the predicted incremental ambient concentrations per se are unlikely to cause any readily measurable deleterious effects on local vegetation, in spite of the prediction of occasional modest exceedences of the 1-hour Canada Maximum Acceptable objective concentration for NO_2 at certain locations within the airshed. An exception is the area on B.C. Hydro property immediately to the NW of BTGP which, because of its proximity, may be subjected to direct plume impingement.

The available evidence indicates that the threshold of response to NO_2 is significantly reduced for some species when they are subjected simultaneously to other pollutants such as SO_2 and ozone, at levels below those defined by the relevant air quality standards or objectives. Hence the occasional occurrence of ambient concentrations of SO_2 which exceed the Canada Maximum Desirable level, and the more frequent occasions on which even the Maximum Acceptable level for ambient ozone is exceeded in the area, suggests that these may, from time to time, coincide with peaks of ambient NO_2 to yield a phytotoxic mixture capable of causing injury to sensitive species. Although no analysis of the frequency of such coincidences in the past is available, other than that based solely upon the magnitudes of the monthly 1-h maxima reported for the relevant Greater Vancouver Regional District air quality monitoring stations, the possibility of such coincidences cannot be ignored. There appears to be no evidence that such coincidences involving present levels of NO_2 have caused plant injury in the past. If such

interactions occur as a result of BTGP 600 MW operation, it is estimated that the effects will be measurable but slight, and take the form of reductions in the growth of several species without any appearance of dramatic symptoms of necrosis or defoliation.

It is not possible to recommend any vegetation monitoring programme which is capable of providing direct and unequivocal early warning of the effects attributable solely to emissions from BTGP, because of the existence of other sources of NO_x in the area. The modest vegetation monitoring programme proposed must be viewed simply as one which will provide information of value on a regional basis only. Although it relates to B.C. Hydro as a contributor to the total burden of oxides of nitrogen in the air shed, its use to provide direct evidence of the impact of BTGP emissions would be totally dependent upon the existence of a meteorological and analytical network capable of defining the specific contributions made by the BTGP plumes at the vegetation monitoring sites.

3.0 AIR QUALITY

Concern for environmental protection has led to the introduction of standards and objectives for air quality in many jurisdictions. In the case of air pollutants, effects on human health, on vegetation, on ecological systems and on materials have been used to determine the average levels of individual pollutants which should not be exceeded over stated time intervals.

With the major global gaseous pollutants, e.g. NO_2, ozone (O_3), sulphur dioxide (SO_2), and hydrogen fluoride (HF), plants in general tend to be more sensitive than animals, and their responses have therefore played an important role in the establishment of such standards and objectives.

Both the thresholds for plant response to air pollutants and the magnitudes of the effects are critically dependent upon the ambient pollutant concentration and its duration (since these define the potential dose). Therefore assessment of the impact of 600 MW operation of BTGP requires the best possible estimates of ground-level ambient air quality in the region, and an appreciation of the relevant air quality standards together with the evidence upon which the standards are based.

3.1 Air Quality Standards and Objectives

In British Columbia, objectives of air quality for several air pollutants have been defined by the Pollution Control Board together with emission standards for various industries. These have been summarized elsewhere (1).

Federal Ambient objectives for NO_2 are as follows:

Maximum Desirable Objective:	annual mean:	60 $\mu g/m^3$ (0.03 ppm)
Maximum Acceptable Objectives:	1-hour:	400 $\mu g/m^3$ (0.21 ppm)
	24-hour:	200 $\mu g/m^3$ (0.11 ppm)
	annual:	100 $\mu g/m^3$ (0.05 ppm)
Maximum Tolerable Objectives:	1-hour:	1000 $\mu g/m^3$ (0.53 ppm)
	24-hour:	300 $\mu g/m^3$ (0.16 ppm)

Maximum desirable levels define long term goals for air quality and provide a basis for anti-degradation policy for unpolluted areas. Maximum acceptable levels are considered to provide adequate protection against effects on soil, water, vegetation, materials, animals, visibility, personal comfort and well being. Maximum tolerable levels denote concentrations that require immediate abatement to avoid further deterioration of air quality such as would pose a substantial risk to public health.

In the context of BTGP, the Canada objectives are the only relevant guidelines for NO_2. The relationships between the Canada Maximum Acceptable objectives for NO_2 and the thresholds for plant response are described in Section 4.1.1. However, because of known interactive effects of NO_2 with SO_2 and ozone (discussed below; Sections 4.2.2 and 4.2.3), assessment of the impact of BTGP's NO_x emissions must also take into account the ambient SO_2 and ozone concentrations.

3.2 Ambient Air Quality Related to BTGP Emissions

Tracer gas studies and computer simulation modeling have led to estimates of the ambient NO_x and NO_2 concentrations likely to occur as a result of 600 MW operation (1). The overall situation regarding the ambient levels of oxidants including NO, NO_2 and O_3 in the Greater Vancouver Regional District (GVRD) has been studied (3), and a detailed analysis of NO_x in the region has been completed (4). These reports, together with summaries of ambient air quality within GVRD (5) and frequency distribution curves for 1-h NO_2 readings for various GVRD monitoring stations and dates (6), have provided the basic dosage information needed for the assessment of impact on vegetation.

3.2.1 Ambient NO_x directly attributable to BTGP

Turning first to the estimates of ambient NO_x concentrations directly attributable to BTGP, the highest 1-hour ambient concentration of NO_x computed from all of the tracer gas studies which would have occurred under 600 MW operation was 560 $\mu g/m^3$ at a location 3 km WSW of BTGP on the south shore of Burrard Inlet. This maximum occurred between 0800 and 0900 PST on September 25, 1979. During the following hour, the NO_x level would have fallen to 350 $\mu g/m^3$.

On no other occasion in the tests conducted in 1979 and 1980 did the estimated NO_x level (based on gas sampling) exceed 300 $\mu g/m^3$ at any location.

The distribution of NO_x maxima based on tracer gas studies and simulation modeling (1, 6) indicates that the greatest ambient concentrations attributable to BTGP operation are likely to occur on the high ground immediately to the N and W of the plant, and on the high ground to the NE, including Anmore (Figure 2).

The significance of these maxima is discussed below (Section 6.1).

3.2.2 Incremental NO_x attributable to BTGP

The incremental burden of NO_x in the Burrard Inlet airshed has also been estimated under conditions of poor plume dispersal by utilizing estimates of NO_x obtained from tracer gas sampling for the sites of GVRD Continuous Air Quality Monitoring Stations, together with GVRD monitoring data for those sites (1). The greatest 1-hour cumulative NO_2 concentrations were predicted to occur at Stations T7 (Anmore School) and T9 (Rocky Point Park). Thus on September 25, 1979, the cumulative NO_2 at T7 with BTGP operating at 600 MW was estimated to be in the range 360 - 440 $\mu g/m^3$, which brackets the Canada Maximum Acceptable objective. BTGP's contribution was estimated to lie within the range 80 - 180 $\mu g/m^3$, a contribution of between 22 and 41% of the total NO_x. On the previous day at T9, BTGP was estimated to have contributed between 30 and 56% of the ambient NO_x, predicted to lie in the range 210 - 270 $\mu g/m^3$.

It therefore appears that 600 MW operation of BTGP may result in occasional exceedences of the Maximum Acceptable 1-hour objective for NO_2 from time to time, on a cumulative basis.

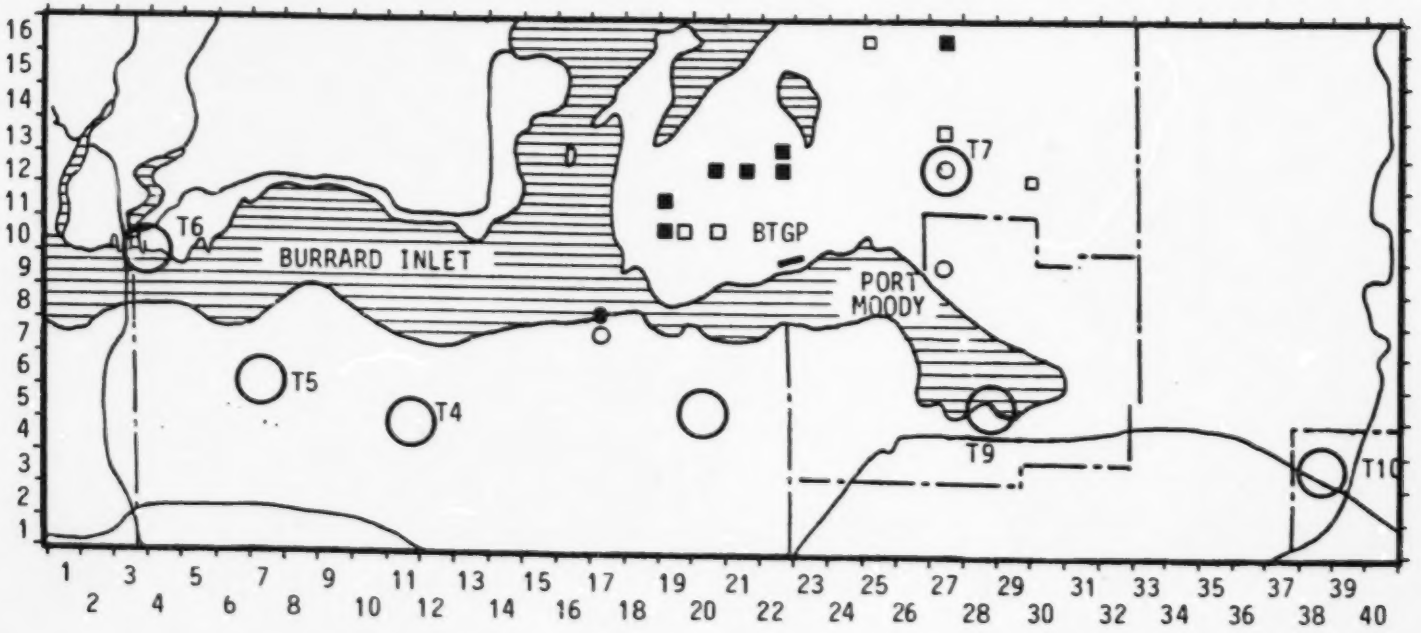
With regard to longer averaging times, review of the GVRD Air Quality Monitoring Data (5) indicates that 24-h average NO_2 levels at Stations T4, T5, T6, T7, T9 and T10 typically ranged between 40 and 100 $\mu g/m^3$ with occasional higher maxima recorded at T4 (172 $\mu g/m^3$; October 1977), T6 (154 $\mu g/m^3$; September 1981), T7 (154 $\mu g/m^3$; October 1979), T5 (134 $\mu g/m^3$; October 1978; October, November 1979; October 1980; January 1981) and T9 (134 $\mu g/m^3$; September 1979).

Figure 2

Map of eastern Burrard Inlet showing GVRD Continuous Air Quality Monitoring Stations, and locations of maximal 1-hour ambient concentrations of NO_x, estimated from tracer gas sampling studies (1)

	sampled	modelled
NO_x > 400 ug/m^3	●	■
NO_x > 200 ug/m^3	○	□

T4 Kensington Park
T5 Confederation Park
T6 Beach Works Yard
T7 Anmore School
T9 Rocky Point Park
T10 Coquitlam Works Yard
T14 Burnaby Mountain



The ratio of 1-h maxima to 24-h maxima for NO_2 for GVRD Stations T4, T5, T6, T7, T9 and T10 at times of plant operation is approximately 1 : 0.45. Furthermore, this ratio is relatively independent of the magnitude of the 1-h maxima, and is less than the ratio between the corresponding Maximum Acceptable objectives (1 : 0.5). The application of the 1 : 0.45 ratio to the 440 $\mu g/m^3$ estimated upper limit for NO_2 at Anmore School (T7) **(1)** leads to an estimated 24-h average of 200 $\mu g/m^3$, the 24-h Maximum Acceptable objective level.

Little information is available on the ambient concentrations of nitric oxide, NO. Based upon limited data for 1980 and 1981 **(4)** there is little apparent correlation between annual mean ambient NO and NO_2 concentrations. However, NO levels were consistently higher during the cooler months (September - March) than they were during the rest of the year, and of particular note is the observation that Anmore School (T7) consistently recorded lower NO concentrations than any other GVRD monitoring site. This, together with the typical bimodal distribution of the 1-h concentrations observed at other sites (with peaks occurring during the morning and evening), suggests the absence from T7 of immediately local sources of NO_x .

3.2.3 Ambient sulphur dioxide

Because of possible interactive effects between NO_x and SO_2 on vegetation, it is important to be aware of the ambient SO_2 situation in the region which may receive BTGP's NO_x emissions. Inspection of the GVRD Ambient Air Quality Monitoring data for 1977 - 1981 **(5)** indicates that the highest ambient SO_2 levels for GVRD stations in the area (see Figure 2), over the five-year period, occasionally exceeded the 1-h or 24-h Maximum Desirable levels. The highest 1-h level, 1300 $\mu g/m^3$, was recorded in February 1980 at Station T7, the station which appears to record somewhat elevated SO_2 levels more frequently than any other station within the network. Thus in the five-year period, eight monthly 1-h maxima greater than 300 $\mu g/m^3$ were reported for T7 (all in the years 1979 - 1981), versus five for T4, three for T9, one each for T5 and T8, and none for T6 and T10. [The 300 $\mu g/m^3$ 1-h level was selected because of its relevence to the NO_2 + SO_2 interactive effects discussed in Section 4.2.2]. However, the occurrence of these maxima appears to be randomly distributed throughout the year, suggesting that they were unusual

episodes. In general, the ambient SO_2 levels throughout the airshed show no marked pattern of change with season. The overall mean maximum 1-h concentration for the six sites for the five years is 145 $\mu g/m^3$, i.e. approximately one-third of the Maximum Desirable objective.

3.2.4 Ambient oxidants (as ozone)

Just as NO_2 and SO_2 interact with regard to effects on vegetation, so NO_2 - oxidant interactive effects may occur, which are independent of the chemical interactions occuring in the atmosphere which lead for example to the conversion of NO to NO_2. GVRD monitoring data (5) clearly indicate that the ambient ozone levels at Stations T4, T5, T6, T7, T9 and T10 regularly exceed the Maximum Acceptable 1-h and 24-h objectives, 160 and 50 $\mu g/m^3$ respectively. On numerous occasions, even the Maximum Tolerable 1-h objective (300 $\mu g/m^3$) has been exceeded appreciably, the highest level reached being 520 $\mu g/m^3$ which occurred at T7 in September 1981. In general, the highest ozone concentrations tend to occur in the summer months, presumably as a consequence of the photochemical action of sunlight, although significant concentrations have also been recorded in spring and fall, and occasionally during winter.

4.0 EFFECTS OF OXIDES OF NITROGEN ON VEGETATION

Recognition of the potentially harmful effects of increased ambient concentrations of oxides of nitrogen on vegetation has received much less attention than the effects of other air pollutants such as SO_2, ozone, and HF. As a result, the literature is sparse, and reviews are few in number. A chapter in the 1977 U.S. National Academy of Sciences review of the nitrogen oxides (2) is devoted to effects on vegetation, and the topic receives relatively brief mention in air pollution texts such as those of Mudd and Kozlowski (7), Guderian (8) and Ormrod (9), and the National Research Council of Canada Report (10). The most comprehensive review is that by Legge et al. (11). Most recently, the writer presented a review at the International Botanical Congress in Sydney, Australia in August, 1981 (12).

The relative scarcity of experimental data related to the effects of NO_x makes the task of attempting to determine the probable occurrence of effects at a particular location extremely difficult. Still greater problems are posed in situations in which it appears that thresholds for response will be exceeded, when one attempts to quantify the response. Unlike the other air pollutants, there are very limited data available on dose-response characteristics to NO_x, and very few plant species have been studied. Hence, it becomes necessary to extrapolate from the limited database, to deal with likelihoods rather than certainties, and to employ judgment rather than hard evidence.

The necessary extrapolations are both aided and hindered by reference to the more extensive knowledge of the effects of other pollutants on plants. Such studies help in the sense that they provide an awareness of the various factors which may influence both threshold and magnitude of response, as discussed below in Sections 4.1.1 and 4.1.2. However, the details of effects of such factors on response to other pollutants may or may not be specifically applicable to the effects of NO_x, because of the inherent differences in the chemical and physical properties of the gases in question, and the fact that their mechanisms of action are different.

In the case of NO_x, an additional complication arises from the fact that two gases, NO and NO_2, are involved, in varying proportions, and both have been shown to exhibit phytotoxicity. Furthermore, because of their chemical nature, both are capable of being converted to nitrate after they have been taken into the plant's foliage, and this may have benefit as a plant nutrient, provided that the ambient concentrations are less than those which cause the threshold for injurious effects to be exceeded.

4.1 Direct Effects of NO_x

4.1.1 Dose-response characteristics of NO_2

Effects on vegetation play a role in the establishment of air quality standards. One technique (13) which has been used to relate such effects to standards involves the compilation of scatter diagrams such as those shown in Figure 3 for NO_2. The numbers on the plots are located at individual dosage combinations (concentration x time) used by different investigators (identified by number) who reported any effect (Figure 3A) or no effect (Figure 3B) on the species investigated. The absence of points close to the ordinate and abscissa support the concept of a hyperbolic threshold response curve, and Figure 3 shows two such curves developed by MacLean (14). The upper curve is the threshold for "acute", or rapid, responses involving foliar injury to the most sensitive species investigated; the lower curve is concerned with subtle or "chronic" effects involving impairment of metabolism or growth of such species, discussed below in Section 4.1.2.

Figure 3 shows clearly that the Canada Air Quality Objectives for NO_2 are less than most of the dosages which have been found to cause effects. Only in the region of relatively long-term exposures (days to months) are there reports suggesting that effects may occur at levels which fall on the interpolated curve connecting the Maximum Acceptable Objective levels of NO_2. Six critical references (15-19) identified in the original work of Young et al. (13) are supplemented by six additional, more recent studies (20-25). Of these, 16, 17 and 25 refer to effects of NO_2 on the levels of certain enzymes in pea, tomato and grass species, effects which in some

Figure 3

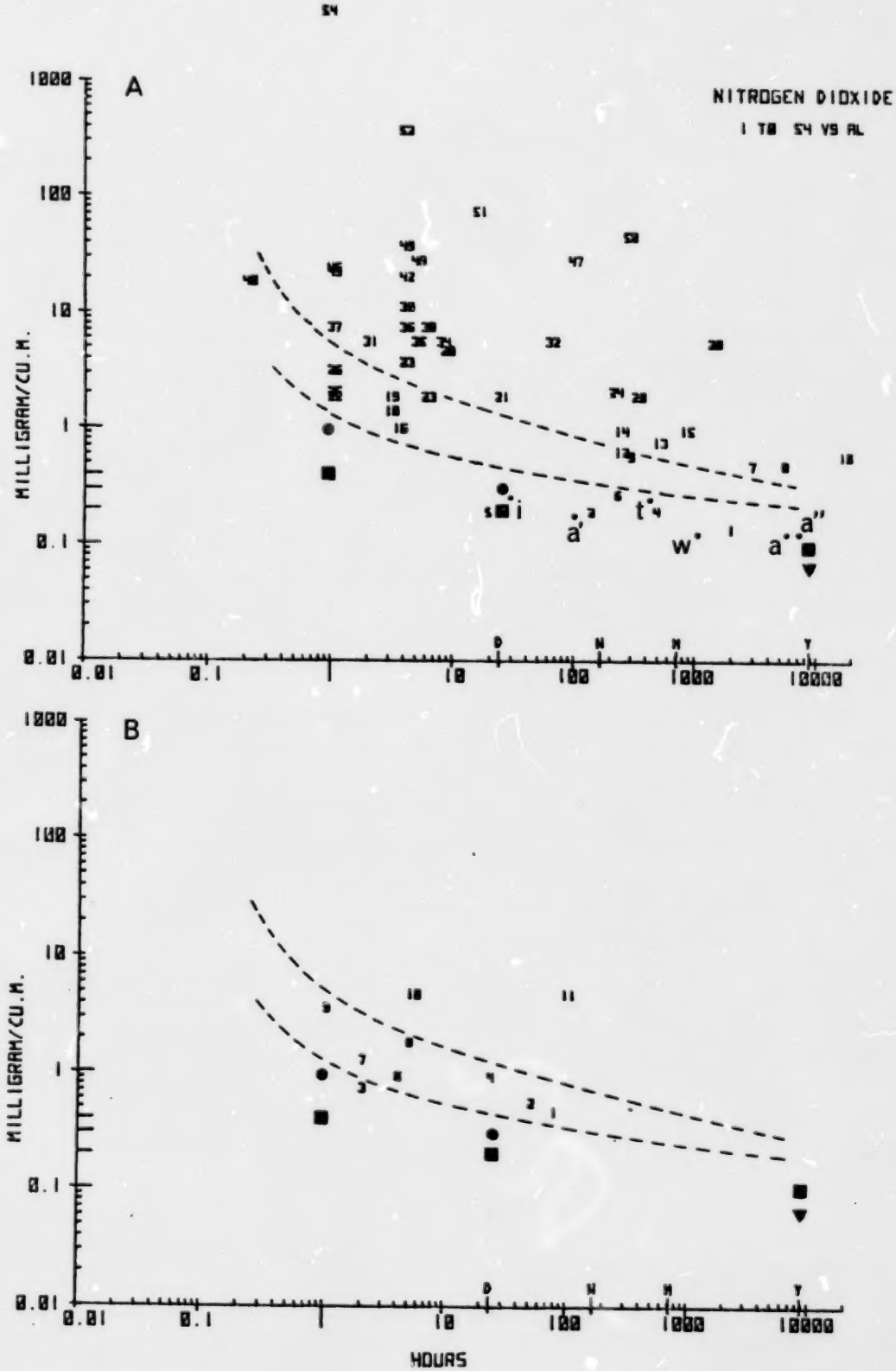
Plots of (A) effect and (B) no-effect data for NO_2 on vegetation. Numbers refer to specific references cited in Young et al. (13). Canada objectives: ●, Maximum Tolerable; ■, Maximum Acceptable ; ▼, Maximum Desirable. Broken lines: upper = threshold for foliar lesions; lower = threshold for metabolic or growth effects (from MacLean, 14).

Key to critical references in (A):

1. Ashenden and Mansfield (15)
2. Horsman and Wellburn (16)
3. Wellburn et al. (17)
4. Wellburn et al. (17)
5. Capron and Mansfield (18)
6. Taylor and Eaton (19)

Points identified by letters in (A) refer to more recent references than those included in Young et al. 13:

a. Ashenden (20)
a'.Ashenden (21)
a".Ashenden (22)
i. Irving et al. (23)
t. Thompson et al. (24)
w. Wellburn et al. (25)


A
NITROGEN DIOXIDE
1 TO 54 VS AL
MILLIGRAM/CU.M.
1000
100
10
1
0.1
0.01
0.01
0.1
1
10
100
1000
10000
B
MILLIGRAM/CU.M.
HOURS

cases appear to confer benefit to the plants. Inhibition of photosynthesis in tomato leaves is reported in 18, and growth inhibitions are reported in 15, 20 and 22 (grasses), 19 (tomato), and 24 (several California desert species). On the other hand, growth stimulations are reported in 23 (soybean) and also in 24 (certain desert species). Increased transpiration is reported in 21 (bean).

These studies therefore show that the threshold for effects of NO_2 lies close to the interpolated Maximum Acceptable objective curve. However, such dosages may be beneficial to certain species.

It should be pointed out that although dosage is a numerical integration of concentration over time, its use in terms of dose-response is somewhat limited because it fails to accommodate the observations that clearly indicate that concentration per se is a more important determinant of response than time of exposure. Thus using the coordinates of Figure 3, all constant dosage lines are straight and possess a negative slope of unity, and it is clear that, for example, a constant dosage of 10 mg NO_2.h/m^3 elicits responses when the duration is less than about 50 hours, but that no response occurs at longer durations, i.e. with concentrations less than 200 µg NO_2/m^3. Nevertheless, bearing this limitation in mind, the dosage concept may provide a means for anticipating effects, where exposures occur over extended periods and involve fluctuating short-term average concentrations.

4.1.2 Types of responses to NO_2

Plants respond to air pollutant stress in a variety of ways. However, regardless of the nature of the pollutant, the foliage is usually the receptor and hence effects are frequently first observed on the leaves. Where a relatively high concentration of short duration has occurred, the response is rapid (1 to 2 days or sooner) and usually takes the form of visible foliar lesions, the so-called "acute" response. The visible appearance of the symptoms is largely a function of the type of air pollutant and to some extent may vary from species to species.

In the case of NO_2, there are no "typical" visible symptoms although they usually occur as interveinal necrotic spots on the leaves, which, depending upon species, may be bleached or turn brown

in colour (16, 27). They closely resemble the markings caused by SO_2; however NO_2-induced symptoms frequently tend to predominate towards the leaf apex and at the margins. On conifers, tan-coloured bands appear on the leaves and needles.

Lower concentrations of longer duration may ultimately result in the appearance of "chronic" visible injury symptoms, or may simply influence physiological or biochemical processes without the appearance of visible changes. In the case of NO_2, chronic visible injury symptoms usually entail a more diffuse distribution of small tan- or bronze-coloured necrotic areas, or may only be revealed in the form of chlorosis. When exposed to dosages below the levels which induce any visible symptoms of injury, leaves frequently appear greener and contain increased amounts of chlorophyll as a consequence of their having metabolized the absorbed NO_2 (19, 31, 40). In some situations this early greening may be followed by subsequent chlorosis and the appearance of necrotic spots.

4.1.3 Range of sensitivity of plants to NO_2

Plant species show wide inherent variability in terms of their response to all types of stress, including that imposed by air pollutants. As a consequence, it has proved to be useful to compile lists of "sensitive" and "resistant" species such as that for NO_2 contained in the National Academy of Sciences report (2). Table 1 is based upon that report, with the addition of some more recent assessments, and is a selection based upon those species likely to occur in the Burrard Inlet region. As pointed out elsewhere (7) the classifications are only approximate because they are based upon subjective criteria from various sources, with most of the reports coming from experimental fumigations conducted at various locations and times of year using different dosages, and employing different methods of assessing response. As a result, such tabulations must be viewed with caution; a species considered to be resistant by one investigator may be considered to be sensitive by another.

It should also be noted that studies with other air pollutants have demonstrated considerable inherent variability in sensitivity even among cultivars within a single species. Although no specific studies have been undertaken with NO_2, it is reasonable to expect that such inter-varietal differences also exist with respect to this pollutant.

Table 1. Sensitivities to NO_2 of Various Plant Species Which May Occur in the Burrard Inlet Region (Based on 2, with additions).

Species	Sensitive	Intermediate	Resistant	Reference
Conifers				
Picea glauca (White Spruce)		*		2
P. pungens cv glauca (Blue Spruce)		*		2
Pinus nigra (Austrian Pine)			*	2
Deciduous Trees and Shrubs				
Acer palmatum (Japanese Maple)		*		2
A. platanoides (Norway Maple)		*		2
Betula pendula (European White Birch)	*			2
Sambucus nigra (Elder)			*	2
Tilia cordata (Little-leaf Linden)		*		2
Fruit Trees				
Malus sp. (Apple)	*			2
Pyrus sp. (Pear)	*			2
Field Crops and Grasses				
Dactylis glomerata (Orchard Grass)	*			15
Lolium multiflorum (Italian Ryegrass)		*		15
Phleum pratense (Timothy)		*		15
Poa pratensis (Kentucky Bluegrass)			*	2
Solanum tuberosum (Potato)		*		2
Trifolium pratense (Red Clover)	*			2
Zea mays (Sweet Corn)		*		2
Garden Crops				
Allium cepa (Onion)			*	2
Apium graveolens (Celery)	*	*		2
Brassica oleracea cv capitata (Cabbage)			*	2
Daucus carota (Carrot)	*		*	2
Lactuca sativa (Lettuce)	*			2
Lycopersicon esculentum (Tomato)	*			2,18
Petroselinum hortense cv humilis (Parsley)	*			2

Table 1 Continued ...

Species	Sensitive	Intermediate	Resistant	Reference
Phaseolus vulgaris (Bush Bean)	*	*		2,21
Pisum sativum (Pea)	*			2
Rheum rhaponticum (Rhubarb)	*			2
Ornamental Shrubs & Flowers				
Antirrhinum majus (Snapdragon)	*			2
Begonia sp.	*			2
Chrysanthemum leucanthemum (Ox-eye Daisy)			*	2
Convallaria majalis (Lily of the Valley)			*	2
Dahlia variabilis (Dahlia)		*		2
Erica carnea (Heath)			*	2
Fuchsia hybrida (Fuschia)		*		2
Gladiolus sp. (Gladiolus)			*	2
Hosta sp. (Plantain Lily)			*	2
Lathyrus odoratus (Sweet (Pea)	*			2
Ligustrum lucidum (Privet)		*		2
Petunia multiflora (Petunia)		*		2
Pyracantha coccinea (Pyrancantha)	*			2
Rhododendron canescens (Azalea)	*			2
R. catawbiense (Rose-Bay)		*		2
Rosa sp. (Rose)	*		*	2
Weeds				
Amaranthus sp. (Pigweed)			*	2
Brassica sp. (Mustard)	*			2
Chenopodium album (Lamb's Quarters)			*	2
Malva parviflora (Cheeseweed)		*		2
Poa annua (Annual Bluegrass) Bluegrass)		*		2
Stellaria media (Chickweed)		*		2
Taraxacum officinale (Dandelion)		*		2

From the species listed in Table 1, it is immediately apparent that there is no mention of the dominant indigenous tree species of the Eastern Burrard Inlet area, i.e. Pseudotsuga menziesii (Douglas fir), Thuja plicata (western Red-cedar), Tsuga heterophylla (western Hemlock), Populus trichocarpa (Northern Black Cottonwood), Betula papyrifera (Western White Birch), Alnus rubra (Red alder), Acer macrophyllum (Broadleaf maple), and Cornus nutallii (Pacific Dogwood), although in a few genera related species are listed. Similarly, there are few references to the wide range of ornamentals planted in the urbanized areas within the region.

Given this lack of specific information, one is therefore forced to approach the question of probable sensitivity of such species by analogy to that of others. Thus, the conifers in general are considered to be in the intermediate or resistant sensitivity classes, as are most of the deciduous trees and shrubs. The most sensitive species tend to be certain vegetable crops, annual ornamentals, grasses, and possibly fruit trees. However, here too, the distribution of the data available (Figure 3) suggests that measurable responses would probably only occur at dosages greater than those defined by the Canada Maximum Acceptable objectives.

An important gap in our knowledge of the range of plant responses to NO_2 concerns effects upon bryophytes, mosses and lichens, although many of these are known to be sensitive, long-term indicators of pollutants such as SO_2.

4.1.4 Direct effects of NO

There have been so few investigations conducted on the effects of NO that a threshold is much less clearly defined than for NO_2. However, there appears to be no evidence to imply that NO is likely to be more phytotoxic than NO_2. The single report to the contrary (18) indicates that photosynthesis in tomato leaves may be slightly inhibited by 127 $\mu g/m^3$ after 20 h. On a mass-equivalent basis, such a dosage would lie just below the 24-h Maximum Acceptable objective level shown in Figure 3A. The few remaining reports indicate that negative growth effects tend to lie at mass-equivalent dosages close to the upper threshold curve in Figure 3A.

No visible symptoms unequivocally attributable to NO have been

observed when all traces of NO_2 have been removed (26).

Similarly, little information exists as to the range of plant sensitivities to NO per se, because of the inherent difficulty of isolating responses which are unequivocally attributable to NO rather than to the trace amounts of NO_2 which are invariably present as a result of the natural oxidation of NO in air.

4.1.4 Factors affecting susceptibility

Independently of the inherent variability in sensitivity to air pollutants among species and cultivars, a wide range of environmental and other factors dictate the susceptibility of individual plants. Although less work has been done on the influence of such factors on plant response to NO_x than with other pollutants, the general principles established for other pollutants are probably applicable. The effects of such factors have been reviewed elsewhere (7, 8, 9, 10, 11), and include time of year; age of leaves and of plants, and phenological stage of development; the influence of biological agents such as pests and diseases; climatic factors, including temperature, photoperiod, light intensity and quality, humidity and wind velocity; CO_2 concentration; and edaphic factors, including soil moisture, temperature, aeration and availability of nutrients.

Almost all of the studies which have been undertaken to examine these effects have involved the use of concentrations and durations of pollutants which elicit appreciable short-term, acute responses, rather than those which induce longer-term, chronic responses.

The overall consequences of the investigations into the effects of these factors may be summarized as follows:

Sensitive species are more susceptible to air pollutants during the growing period than during periods of dormancy;

Age of leaf tissue dictates the nature of acute response to NO_x with youngest leaves showing necrotic injury, while oldest leaves merely exhibit chlorosis (2);

In broadleaved deciduous species, the middle-aged or oldest

leaves are most susceptible to NO_2, whereas in conifers, the emerging needles are the most susceptible (2);

With NO_2, plants are frequently more susceptible to exposures at night than during the day (bean, alfalfa, sugar beet) (2); this in turn leads to the suggestion that susceptibility is increased at low light intensities (11);

Increased temperatures increase metabolic rates and hence high temperatures may accelerate and magnify the effect of NO_x, although no studies have been undertaken to validate this suggestion (11);

Relative humidity tends to increase the effects of air pollutants, but this has not been confirmed for NO_x (11);

Wind speed tends to increase response to all pollutants by reducing the boundary layer resistance to uptake (11);

CO_2 concentration may reduce the impact of pollutants by causing partial closure of stomata and thus reducing pollutant uptake (29);

Increased soil moisture stress reduces susceptibility to NO_x (2), as is the case with other pollutants;

Soil fertility affects susceptibility to air pollutants in many different (and often contradictory) ways (11); susceptibility has been shown to decrease with increased soil nitrogen supply (bean, 30); growth (tomato, 31) and yield (soybean, 23) may be increased by low dosages of NO_2 in plants receiving adequate soil-N.

The relevance of these effects on the impact of BTGP emissions on local vegetation is discussed in Section 6.0.

4.2 Interactive Effects of Mixtures of Air Pollutants

Although the bulk of the published information on the effects of air pollutants on plants concerns individual pollutants, the growing recognition that pollutants rarely occur singly in nature has led to increased attention being directed towards the effects of mixtures. Recent reviews of this topic include those by Runeckles **(32, 33)**, McCune **(34)** and Ormrod **(35)**, while earlier reviews are included in **2, 7, 8, 9, 10** and **11.**

The particular combinations which have received the most attention are SO_2 + NO_2 and SO_2 + ozone, and these studies have demonstrated that the effects of combinations can take a variety of forms ranging from antagonistic (less than additive), to synergistic (greater than additive) responses. Between these extremes, pollutants may act independently and elicit additive responses.

In the context of BTGP emissions, the interactions which are of potential importance are those between the components of NO_x itself, i.e. NO and NO_2, between NO_x and SO_2, between NO_x and ozone, and between NO_x, SO_2 and ozone.

4.2.1 Oxides of nitrogen

Few studies have been undertaken to investigate potential interactions between NO and NO_2, largely because of the difficulty of preventing the natural oxidation of NO leading to the formation of NO_2. As a result of this oxidation, it must be concluded that experiments with NO probably involve trace amounts of NO_2, even though precautions have been made to minimize this conversion. Thus when NO_2 was rigorously scrubbed from air containing NO, no visible symptoms of injury occurred until high concentrations of NO were used (> 30 mg NO/m^3) **(11)**, although lower concentrations (760 µg/m^3) cause reversible inhibition of photosynthesis (oats, alfalfa) **(36)**.

Regardless of the mechanism whereby NO causes a response, the only studies undertaken to investigate the effects of NO + NO_2 mixtures suggest that the effects on inhibition of photosynthesis in oats and alfalfa **(36)** and tomato **(18)** are essentially additive. In tomato, the threshold for response under the greenhouse conditionsused was approximately 120 µg NO/m^3 + 190 µg NO_2/m^3 (20-h exposure). However these experiments were conducted at ambient CO_2

levels (330 ppm), and when CO_2 enrichment to 1000 ppm was employed, the threshold for growth reduction was raised to approximately 120 µg NO/m^3 + 760 µg NO_2/m^3 **(37)**. At levels of 500 µg NO/m^3 + 760 µg NO_2/m^3, maintained for 19 days, total growth was reduced more than 50% in spite of the ameliorative effect of CO_2. Subsequent experiments with the same tomato cultivar (Ailsa Craig) showed that the effects of 500 µg NO/m^3 (+ traces of NO_2) were completely suppressed by increasing the CO_2 level to 1000 ppm, and that considerable intervarietal differences occurred, with some cultivars being stimulated by 500 µg NO/m^3 **(38)**.

4.2.2 Sulphur dioxide

Interactive effects of NO_x and SO_2 have only been studied with NO_2 + SO_2 mixtures. Many of the early studies resulted in quantitatively inconsistent findings, although there was a predominance of synergistic effects, which suggest that the threshold for visible injury to highly sensitive species is of the order of 100 µg NO_2/m^3 + 130 µg SO_2/m^3, for 4-hour exposures **(39)**. However, it must be stressed that this threshold may be artifically low since all these experiments were conducted under conditions which maximized susceptibility, and studies under field conditions have suggested that thresholds in nature are considerably higher. Thus no synergism could be detected with many desert species, and combined dosages greater than 2000 µg/m^3 for 2 hours were required to induce visible injury in the most sensitive species **(40)**. More recently, another investigation of desert species under field conditions has shown that growth inhibitions may occur at concentrations of 630 µg NO_2/m^3 + 1,750 µg SO_2/m^3 when exposures 7-h per day were continued for 16 weeks **(24)**. In this latter study, lower concentrations (210 µg NO_2/m^3 + 580 µg SO_2/m^3) over the same period either had no significant effect on growth, or induced growth stimulations. Recent studies involving field fumigations of soybeans **(23)** show clearly that dosages (based upon ten 2.5-h fumigations over a 30-day period) resulting from 420 µg NO_2/m^3 + 393 µg SO_3/m^3 and 248 µg NO_2/m^3 + 445 µg SO_2/m^3 caused 11% and 18% reductions in yield respectively, although no reductions occurred at the corresponding dosages of the single pollutants. Indeed, in several instances of the latter, modest growth stimulations occurred.

Recent long-term studies of the effects of NO_2 and SO_2 on the growth of grasses (15, 20, 22) have shown that intermittent exposures to 210 µg NO_2/m^3 + 288 µg SO_2/m^3 averaging 130 and 178 µg/m^3 respectively per week for 20 weeks resulted in synergistic or additive reductions in the dry weights and leaf areas of Dactylis glomerata (Orchard grass), Lolium multiflorum (Italian ryegrass), Phleum pratense (Timothy) and Poa pratensis (Kentucky bluegrass), which, in the case of the first three species, were clearly demonstrable some considerable time prior to the first harvest at 4 weeks. In the cases of D. glomerata, L. multiflorum and Phleum pratense, synergism was pronounced and resulted in 78, 52 and 86% dry weight reductions respectively. Dry weight of Poa pratensis was reduced 84%. Ashenden and Mansfield (15) speculate therefore that exposures to such relatively low concentrations could rapidly give rise to changes in the species composition of pastures sown to mixed grasses, although they rightly point out that prediction of the consequences of such exposures under field conditions (their experiments were conducted in greenhouses) would require much more extensive knowledge of the variation of response within each species.

4.2.3 Ozone

Little information is available about the interactive effects of NO_x and ozone, although relatively high concentrations of NO_2 and ozone have been reported to be antagonistic (2). On the other hand, exposures to daily sequences involving NO_2 and ozone at concentrations of 190 µg NO_2/m^3 and 190 µg O_3/m^3 have been found to act synergistically in radish and wheat, and antagonistically in beans (41).

A complex investigation of the interactive effects of SO_2, NO_2 and ozone on radish growth (42) revealed that the three pollutants tended to act additively in reducing growth 35%, under conditions in which 382 µg NO_2/m^3, 524 µg SO_2/m^3 and 392 µg O_3/m^3 concentrations lasting 3 - 6 h were used.

5.0 VEGETATION IN THE REGION

The terrestrial vegetation in the region surrounding the eastern end of the Burrard Inlet, consists of both natural coastal forest and an extremely diverse mixture of horticultural species associated with urban development. The natural coastal forest areas are outlined in Figure 4, and occur primarily in the sector covering the NW, N, NE and E from BTGP and to the S and SW, on Burnaby Mountain.

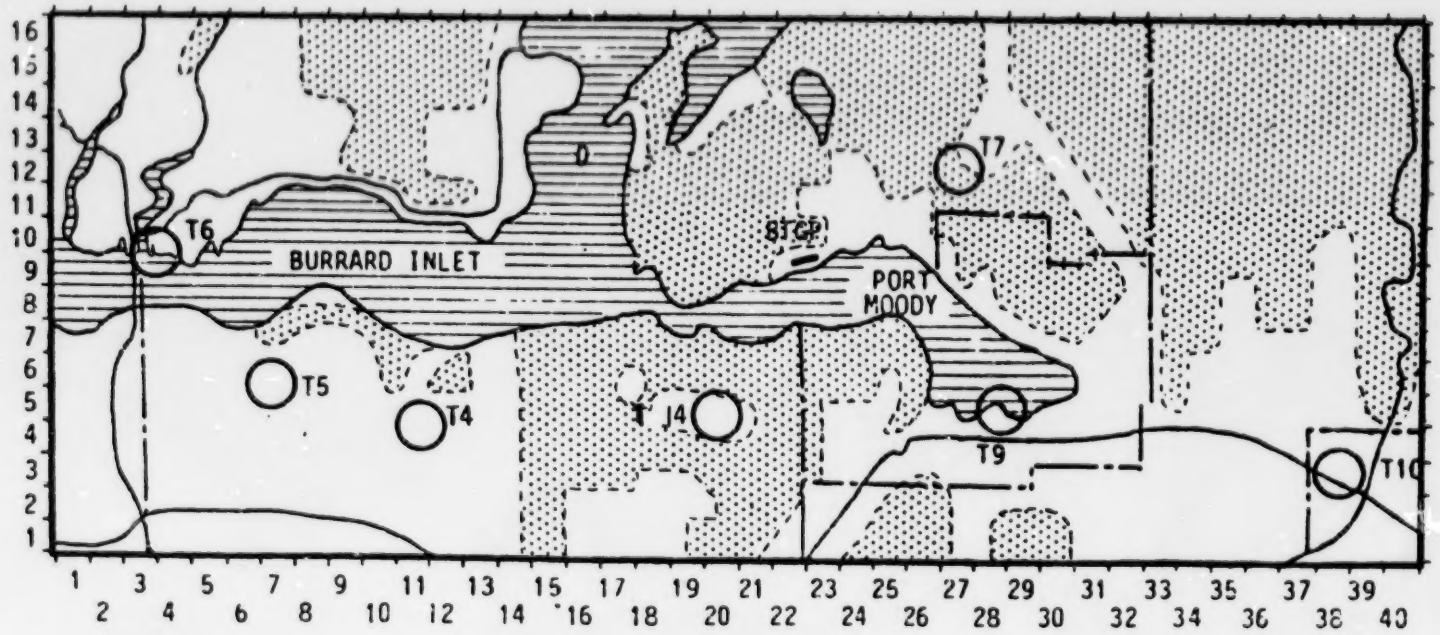
The natural coastal forest consists of second generation coniferous and broadleaved trees, the primary growth having been removed by logging before the turn of the century. The dominant conifers are Pseudotsuga menziesii (Douglas fir), Thuja plicata (Western Red-cedar), Tsuga heterophylla (Western Hemlock). On the edges of natural clearings, roadways, creek banks, etc. decidious trees frequently dominate or are mixed with the conifers. These include Populus trichocarpa (Northern Black Cottonwood), Betula papyrifera var comutata (Western White Birch), Alnus rubra (Red alder), Acer macrophyllum (Broadleaf maple), and the occasional Cornus nuttallii (Pacific Dogwood).

Exposed rock faces, e.g. to the NW of BTGP, where the soil pockets are too shallow to support tree growth, bear a broken cover of shrubs such as Spiraea menziesii (Hardhack), Gaultheria Shallon (Salal) and introduced Cytisus scoparius (Broom). On such sites, and recently disturbed slopes, mosses (Polytrichum spp. dominate) constitute the ground cover.

In the developed areas, some indigenous coniferous trees have been retained, e.g. Douglas fir, cedar and hemlock, and other conifers have been planted, including Picea pungens cv glauca (Blue spruce) P. abies (Norway spruce), Pinus nigra (Austrian pine), P. sylvestris (Scots pine), Thuja occidentalis (White-cedar) and T. orientalis (Oriental cedar). Coniferous shrubs include Chamaecyparis lawsoniana (Lawson's False Cypress; numerous selections), Juniperus chinensis (Chinese Juniper, including the widely planted, low-growing "Pfitzeriana"), J. communis (Common Juniper; numerous selections) and J. scopulorum (Western "Cedar"; including 'Blue Haven').

Figure 4

Map of eastern Burrard Inlet showing extent of natural coastal forest vegetation (stippled areas). Clear areas indicate residential and industrial land, and urban parks.



Introduced broadleaf, deciduous trees include Populus nigra var italica (Lombardy Poplar), Acer platanoides (Norway Maple), A. palmatum (Japanese Maple; several selections), Salix babylonica (weeping willow), Betula pendula (European White Birch) and a wide range of Malus spp. (Apple), Pyrus spp. (Pear), and Prunus spp. (Cherry). Prominent shrubs include Rhododendron spp., Photinia serrulata, Pyracantha spp. (Firethorn), Cotoneaster spp., Viburnum spp., Pieris spp. and Hydrangea spp.

A photographic record indicating some of the vegetative diversity of the region is included in Appendix B.

6.0 ASSESSMENT OF PROBABLE IMPACTS OF OXIDES OF NITROGEN EMITTED BY BTGP

The preceding sections have dealt with the probable consequences of BTGP operation on the concentrations of oxides of nitrogen in ambient ground-level air in the eastern Burrard Inlet region, the known effects of oxides of nitrogen on vegetation, including interactive effects with other air pollutants, and the nature of the vegetation in the region. In assessing the probable effects of the BTGP emissions, two questions must be answered:

1. Are the ambient ground-level NO_x levels likely to exceed the thresholds for response by the vegetation in the region?

2. If the thresholds are likely to be exceeded, what is the probable magnitude and type of response to be expected?

These questions are addressed systematically below, firstly by assessing the effects, if any, of the present ambient air quality, with intermittent BTGP operation, and secondly by assessing the incremental effects of 600 MW BTGP operation. In each situation, the assessment is subdivided into visible, short-term responses and longer-term subtle and chronic effects.

6.1 Assessment of Impact under Present Conditons

6.1.1 Visible, short-term effects

As pointed out in Section 4.1.1, the probable threshold for acute, visible foliar lesions is close to the upper curve depicted in Figure 3A, for a range of sensitive species growing under conditions which enhance their susceptibility. This threshold curve indicates that 1-hour NO_2 concentrations greater than approximately 5000 $\mu g/m^3$ would be required to induce foliar lesions. If one assumes that some species which occur in the region (but whose sensitivity to NO_2 is unknown) may have thresholds which are lower by a factor of two, this threshold dosage is reduced to 2500 $\mu g/m^3$. However, such a threshold would only be relevant if the species were growing under conditions favouring susceptibility, an unlikely situation for plants under field conditions, as discussed in Section 4.1.3. Nevertheless, if one also assumes maximum susceptibility,

then the maximum ambient NO_2 situation observed with or without intermittent BTGP operation during the past few years, i.e. 470 $\mu g/m^3$ (1-hour) at GVRD Station 7 (Anmore School) in October 1979 (5), is clearly well below threshold; its occurrence late in the growing season also argues against significant impact.

If one assumes an average situation in which an equal concentration of NO is also present and that NO and NO_2 are equally phytotoxic (which as pointed out in Section 4.2.1 may be valid for short-term reversible inhibition of photosynthesis but probably over-estimates the relative toxicity with respect to other effects) the observed maximum is still well below the 1-h threshold.

However, the possible interactive effects of NO_2 and other pollutants must also be considered. The most sensitive species have been reported to be visibly injured by 4-hour exposures to concentrations as low as 188 $\mu g\ NO_2/m^3$ + 262 $\mu g\ SO_2/m^3$ (39). No analysis of the individual 1-h levels of NO_2 and SO_2 obtained by GVRD monitoring has been undertaken and hence it is not known whether there have been occasions on which the 1-h peak concentrations of the two gases coincided. Nevertheless, the possibility of such coincidences is suggested by inspection of the GVRD tabulations of monthly 1-h maxima (5), which reveals that such levels (188 $\mu g\ NO_2/m^3$ + 262 $\mu g\ SO_2/m^3$) of the <u>individual</u> pollutants were exceeded at least once at the stations indicated during the following months:

Station T4, Kensington Park:
- 1977: February, April
- 1978: April, June
- 1979: January, September
- 1980: September
- 1981: October

Station T5, Confederation Park:
- 1979: January, November

Station T6, Beach Yard:
- 1977: December
- 1979: January

Station T7, Anmore School
1979: June, September, October
1980: September
1981: October

Station T9, Rocky Point Park:
(no occasions)

Station T10, Coquitlam:
(no occasions)

It should be noted that several of these occurrences are during the winter months, at which time much of the perennial vegetation is dormant and unlikely to respond dramatically. However, it should also be noted that in two of these months, the maximum 1-h ambient ozone concentrations reached 300 $\mu g/m^3$ (June 1979, T7; September 1979, T4), but again, no analysis has been conducted of the GVRD data to determine whether or not individual peaks of ozone, NO_2 and SO_2 coincided.

The possible occurrence of such potentially phytotoxic combinations of NO_2 and SO_2 and ozone suggests that, if the vegetation growing at such locations is as sensitive and susceptible as that used experimentally to investigate dose-response characteristics and interactive effects, then such vegetation might be expected to reveal symptoms of injury, or have been reported to have been injured in the past. To the writer's knowledge, no such reports have occurred.

With regard to the possibility of injury having occurred during the summer of 1981, a field investigation was undertaken, and is described below (Section 6.1.3).

6.1.2 Longer-term effects

Reference to the recent response data shown in Figure 3A indicates that the most sensitive species, growing under conditions of maximum susceptibility would require exposures to NO_2 ranging between approximately 200 $\mu g/m^3$ (24-hour) and 100 $\mu g/m^3$ (annual) for chronic growth effects to occur. Reference to GVRD data (5) indicates that during the period 1977-1981, the highest 24-h average

NO_2 concentrations occurred in October 1977 at Kensington Park (T4; 170 $\mu g/m^3$), in October 1979 at Anmore School (T7; 150 $\mu g/m^3$) and in September 1981 at Beach Yard (T6; 150 $\mu g/m^3$). While these are below the threshold, there is less room for incremental additions than was the case with regard to visible injury, although their occurrence late in the growing season again argues against significant effect.

However, the presence of concomitant SO_2 may reduce the threshold appreciably, and more specifically may also counteract the beneficial effects of either the NO_2 or SO_2 alone **(23)**. Thus for sensitive grasses, **(15)** repeated daily exposures to 130 μg NO_2/m^3 + 178 μg SO_2/m^3 significantly reduced growth. Furthermore, soybean yields were significantly reduced by NO_2 + SO_2 exposures which appear to have averaged as little as 55 $\mu g/m^3$ and 64 $\mu g/m^3$ respectively on a 24-hour basis, probably as a result of accelerated chlorosis and senescence of the leaves **(23)**. However, these mean values are somewhat misleading since the effects reported were probably induced by the exposures to the higher concentrations (lasting only 2.5 or 2.9 hours) which constituted the experimental regime.

GVRD data **(5)** indicate that there were no occasions during 1977-81 on which the maximum 24-h SO_2 level reached 178 $\mu g/m^3$ during months reporting maximum 24-hour NO_2 averages which approached or exceeded 130 $\mu g/m^3$. The highest combined values were 150 μg NO_2/m^3 and and 100 μg SO_2/m^3 at Station T7 in October 1979. This appears to have been an isolated occurrence; the monthly means are unexceptional.

The patterns of recent, longer-term averages for NO_2 and SO_2 therefore provide little reason to expect significant effects on growth or evidence of chronic injury.

6.1.3 Field investigations

Because of the possibility that BTGP emissons might be causing injury to vegetation in the region, and particularly on the high ground immediately N of the plant, a preliminary survey was undertaken in early 1981 by B.C. Hydro personnel **(43)**. Vegetation was inspected at the sites identified on Figure 5. Given the difficulties of attributing symptoms to NO_2 (discussed above,

Section 4.1.2) only at Site 5 (on B.C. Hydro property) were foliar symptoms observed which suggested that emissions from BTGP might have been involved. The evidence was partly circumstantial; BTGP plumes were reported to have been seen to impinge directly on the area (42), and the chlorosis or necrosis of the foliage observed on Pseudotsuga menziesii (Douglas fir), Tsuga heterophylla (Western Hemlock) and Thuja plicata (Western Red-cedar) was on the side of the trees facing BTGP. However, the authors (43) point out that, in their opinion, "one cannot conclude that these symptoms are a direct or indirect result of emissions from BTGPμ.

In order to confirm these observations, and to inspect the vegetation in other locations where a combination of information (tracer gas release studies, topography and meteorology) suggested that impacts might occur, the writer made additional field investigations in late September 1981. Sixteen sites were selected, including five of the seven sites inspected in January 1981 (43). Their locations are shown in Figure 6. Descriptions of the sites and comments on the appearance of the vegetation are included in Appendix A.

Again, only at Site 5 (Figures 5 and 6) were defoliation and various types of chlorosis and discoloration of the foliage of the indigenous conifers observed. At other locations, including Site 10, Anmore School, the occasional appearance of necrotic lesions or chlorotic symptoms on coniferous or deciduous trees or on shrubs and herbaceous species was probably attributable to edaphic or meteorological factors (such as winter injury in exposed locations) or to the presence of pathogens. With regard to Site 5, no obvious signs of impaired growth were observed on other vegetation, including mosses and lichens on exposed rock faces. Nevertheless, the proximity to BTGP, the occurrence and location of the defoliation, die-back and chlorosis and necrosis of the foliage on the conifers strongly suggest a role for BTGP plume impingement as a significant contributor to these symptoms, even on these marginal sites. Such trees, with their normally persistent foliage, are frequently better long-term indicators of air pollutant injury than deciduous or annual species that may be inherently more sensitive but may not be at a susceptible stage of development at the time of exposure.

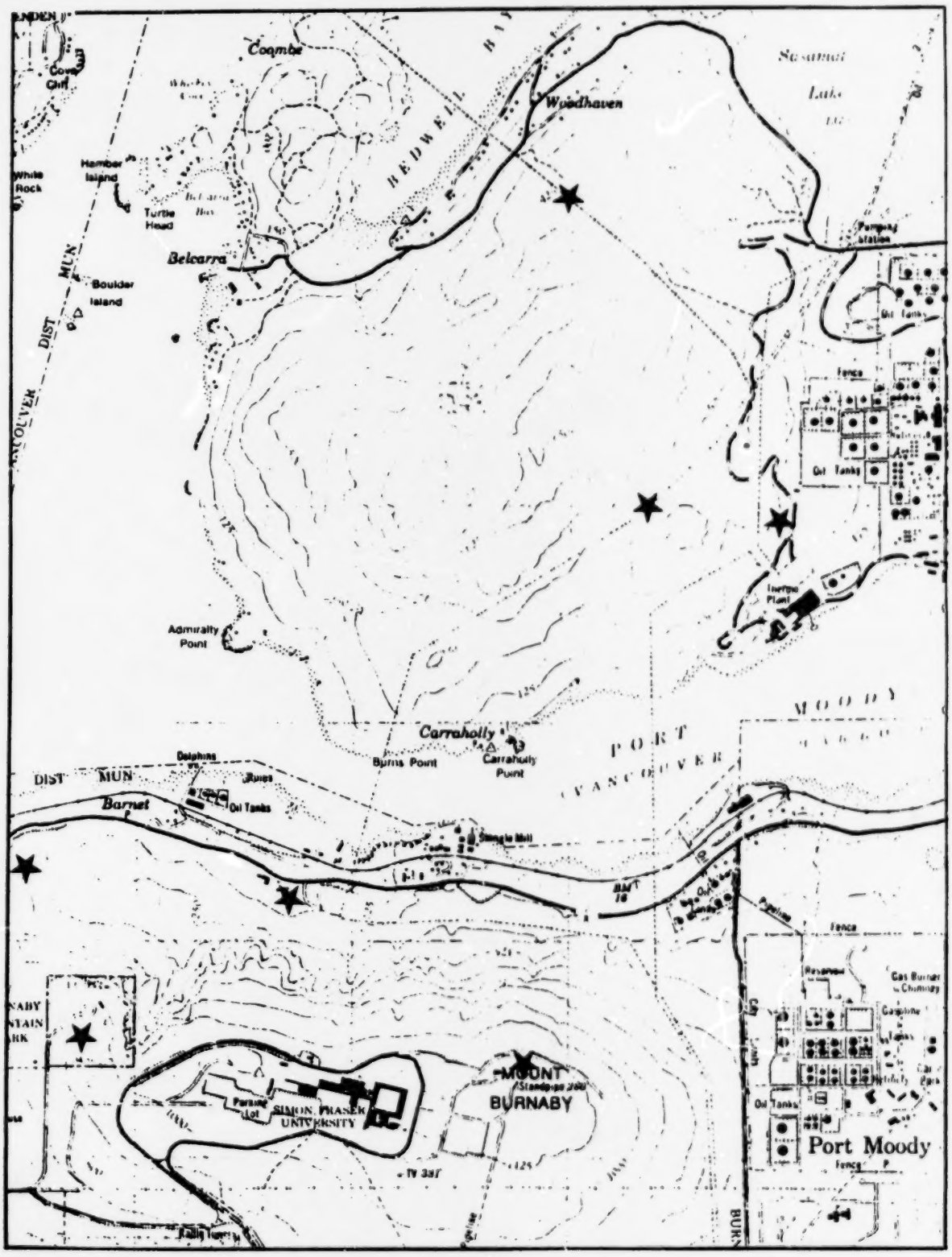


Figure 5. Sites inspected by B.C. Hydro personnel, January 1981 (43)

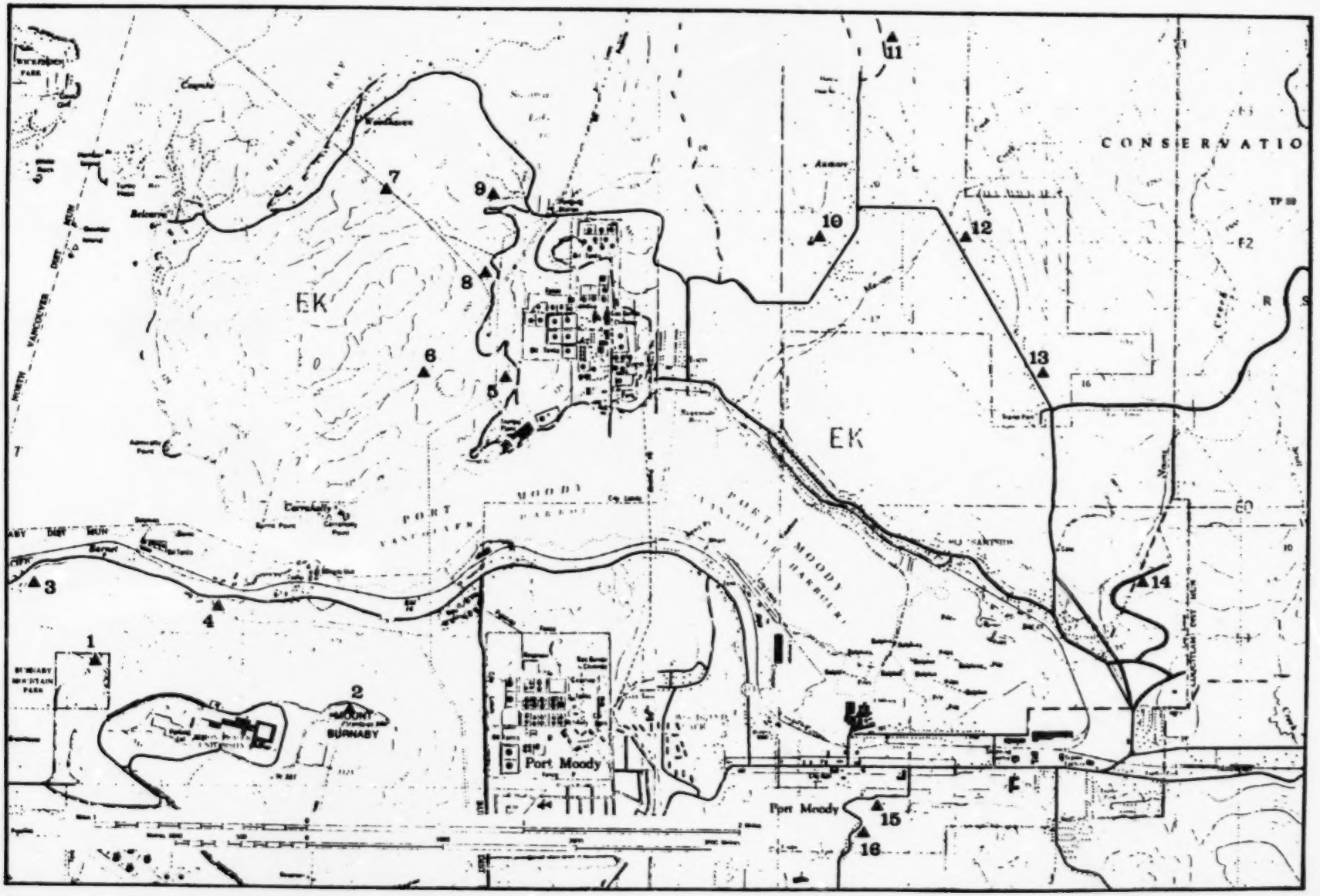


Figure 6. Map showing locations of Sites 1 to 16, inspected September 1981. Sites 6 & 7 were inaccessible (but see 43)

The absence of any clearly obvious effects of the present and recent ambient concentrations of NO_2, SO_2 or ozone (other than at Site 5) suggests that the dominant indigenous species and the wide range of horticultural species planted throughout the residential areas are inherently less susceptible to impact, than those which have been experimentally reported to be sensitive to NO_2 alone or in combination.

6.2 Assessment of Incremental Impact Due to BTGP Operation

The absence of any clear evidence of effects of present ambient air pollutant levels on the region's vegetation, and the predicted magnitudes of the incremental additions of NO_x if BTGP were to be operated under 600 MW conditions, suggests that such operations would be unlikely to result in any widespread deleterious effects on vegetation, directly attributable to NO_x. In Section 3.2.2, reference was made to 440 µg NO_2/m^3 as the upper limit of 1-h concentrations expected to occur with BTGP operating at 600 MW. This is approximately 6% less than the maximum 1-hour value recorded by GVRD (Station T7, October 1979), but exceeds the Canada Maximum Acceptable objective level by 10%. In the event that such a level was sustained so as to result in a 24-hour average of 200 µg/m^3 (using the 1 : 0.45 ratio discussed in Section 3.2.2), the combination of dosages moves close to the threshold above which injury and growth effects are likely to occur. The occurrence of such 1-h and 24-h concentrations of NO_2 alone or accompanied by NO would probably not result in any readily measurable effects on vegetation. However, these concentrations are uncomfortably close to the thresholds at which adverse effects have been observed (Figure 3A), and this assessment places great weight on the accuracy of the threshold curve. If any direct responses to NO_x were to occur, they would probably be found in the areas of Site 5 (NW of BTGP) and Site 12 (Anmore School). Any such effects would be the consequence of periods of fumigation, occurring under atmospheric conditions which result in poor dispersal of the BTGP emissions. The fact that such conditions tend to occur late in the year at the end of the growing season would tend to minimize the possibility of measuring significant effects.

If such concentrations of NO_2 were to be accompanied by elevated SO_2 and ozone levels, there is some evidence that the combinations

could be phytotoxic. In this regard, the area around Anmore School appears to be the most vulnerable, since historically it has been subjected to elevated levels of both SO_2 and ozone, as well as being the location of the greatest projected NO_x concentration from 600 MW BTGP operation. The Port Moody area, close to Rocky Point Park, may also be subjected to possibly phytotoxic combinations.

With regard to the magnitudes of these impacts, these will in part be the outcome of two effects which tend to counteract each other. Firstly, direct impingement of admixtures of NO_2 with SO_2 and ozone might cause small but measurable deleterious effects on some species, probably conifers, grasses and some backyard fruit trees and vegetables. Secondly, because at most times of year the monthly 1-h maxima of NO_2 and SO_2 recorded by GVRD **(5)** tend not to coincide, there will be occasions when these peaks will occur individually, and such occurrences have been shown to be capable of stimulating plant growth **(23)**. It then becomes a question of judgment as to which of these effects may predominate. Because there is considerably more evidence to support synergistically injurious effects than individual stimulations, prudence would suggest that injury might outweigh benefit. Combining these factors leads to the conclusion that, in the worst anticipated situation, with NO_2 exceeding the 1-h Maximum Acceptable objective coincidentally with elevated levels of SO_2 and ozone, some adverse effects on plant growth are likely, but would probably be at the limit of measurement for most species. Possible exceptions are perennial grasses and certain vegetable and ornamental species, in which mild reductions of growth might just be detectable. The likelihood that coincidental exposures to NO_2, SO_2 and ozone occur mainly in spring and fall would act to mitigate the effects on annual species.

Finally, although this assessment indicates that the effects of ambient NO_x are more likely to be measurable as a result of synergistic action with other ambient pollutants than as a result of exposure to NO_x alone, the attribution of any such effects to BTGP emissions rests solely upon the projections of maximum ambient NO_x levels from 600 MW operation **(1)**.

7.0 MONITORING PROGRAMME

Vegetation monitoring programmes may be used "to warn of possible damage to natural or cultivated plants and to raise the alarm concerning possible risks to man, animals and materials from specific air pollutants to which plants are (much) more sensitive" (44). Such programmes do not replace but complement physical and chemical measurements of ambient pollutant concentrations because they focus on effects and provide an integration of "the influences of intrinsic plant properties, exposure times, concentrations of pollutant and external and internal conditions of the plants" (44). While both indigenous and cultivated species may serve as useful indicators, the problem of pollutant interactions makes it essential wherever possible to use a range of species each of which is selected for its sensitivity to one of the pollutants likely to be present in the ambient air. In addition, since environmental conditions affect susceptibility markedly, it is also desirable to standardize at least the soil, water and mineral nutrient supply to the indicator plants.

Unfortunately, and in contrast to the situation with pollutants such as ozone, SO_2 and HF, no species has yet been reported to be useful as an indicator for NO_2 (or NO), either with regard to short-term, acute injury responses, or to long-term growth effects. In the former situation, the lack of typical foliar symptoms (discussed in Section 4.1.2) is part of the problem, while in the latter case, the problem is caused by the ability of many (or all) plants to derive some nutritional benefit from low ambient concentrations of NO_2.

In the specific context of BTGP emissions of NO_x, the previous sections of this report have led up to the prediction of minimal measurable effects of NO_x per se on local vegetation, and the possibility of small but measurable effects if occasional NO_2 peaks coincide with elevated ozone and/or SO_2 levels. The magnitudes of these possible impacts of NO_x on vegetation, and the desire to use such a programme to provide an early warning system, requires that the most sensitive species or cultivars are grown, and that they are grown under conditions which enhance their susceptibility to the fullest. However, since there is a dearth of precise information about sensitivity of species to NO_x, a monitoring programme should include observations on major indigenous species.

It should also be pointed out that, although the incremental effect of 600 MW BTGP operation on ambient NO_x levels in the airshed has been assessed (1, 5), numerous other sources of NO_x exist in the region. At best, a vegetation monitoring programme such as the one proposed can only be related to air quality on a regional scale. No such programme can, by itself, unequivocally provide advanced warning of the effects of emissions from a particular source such as BTGP. As a result, the vegetation monitoring programme proposed is only indirectly related to BTGP operation, and logically belongs within a larger programme which focusses not only on NO_x but on other pollutants within the region, especially ozone.

The programme proposed below has been developed in the light of these various factors. It is a modest programme which involves monitoring at only three sites at which it is considered possible for impact due to NO_x to be measurable, together with two control sites. The sites have been selected on the basis of past ambient air quality information and the projections for 600 MW operation of BTGP. The programme includes two components: sites in selected locations at which indigenous vegetation can be observed on a continuing basis for visible symptoms; and additional sites at suitable locations at which species sensitive to the mixture of air pollutants to which BTGP emissions contribute can be planted and observed. For each type of site, appropriate control sites are also proposed which, for the indigenous species, duplicate as far as possible the characteristics of the monitoring sites (i.e. soil type, hydrology, nutrient availability, aspect, slope, vegetative cover, etc.). Two of the sites are close to locations at which air quality monitoring for NO_2, SO_2 and ozone is being carried out.

The assessment of the probable impact of 600 MW BTGP operation suggests that effects on vegetation are most likely to occur immediately to the NW of BTGP, in the Anmore School area and possibly in Port Moody. In particular, the sites adjacent to Anmore School and Rocky Point Park should include standardized plant cultivation systems such as that used in the Netherlands (44) in order to achieve the maximum susceptibility needed for the monitoring programme to have early warning capability. A corresponding system should also be installed at one of the control sites.

The specific sites are located as shown in Figure 7. Some of

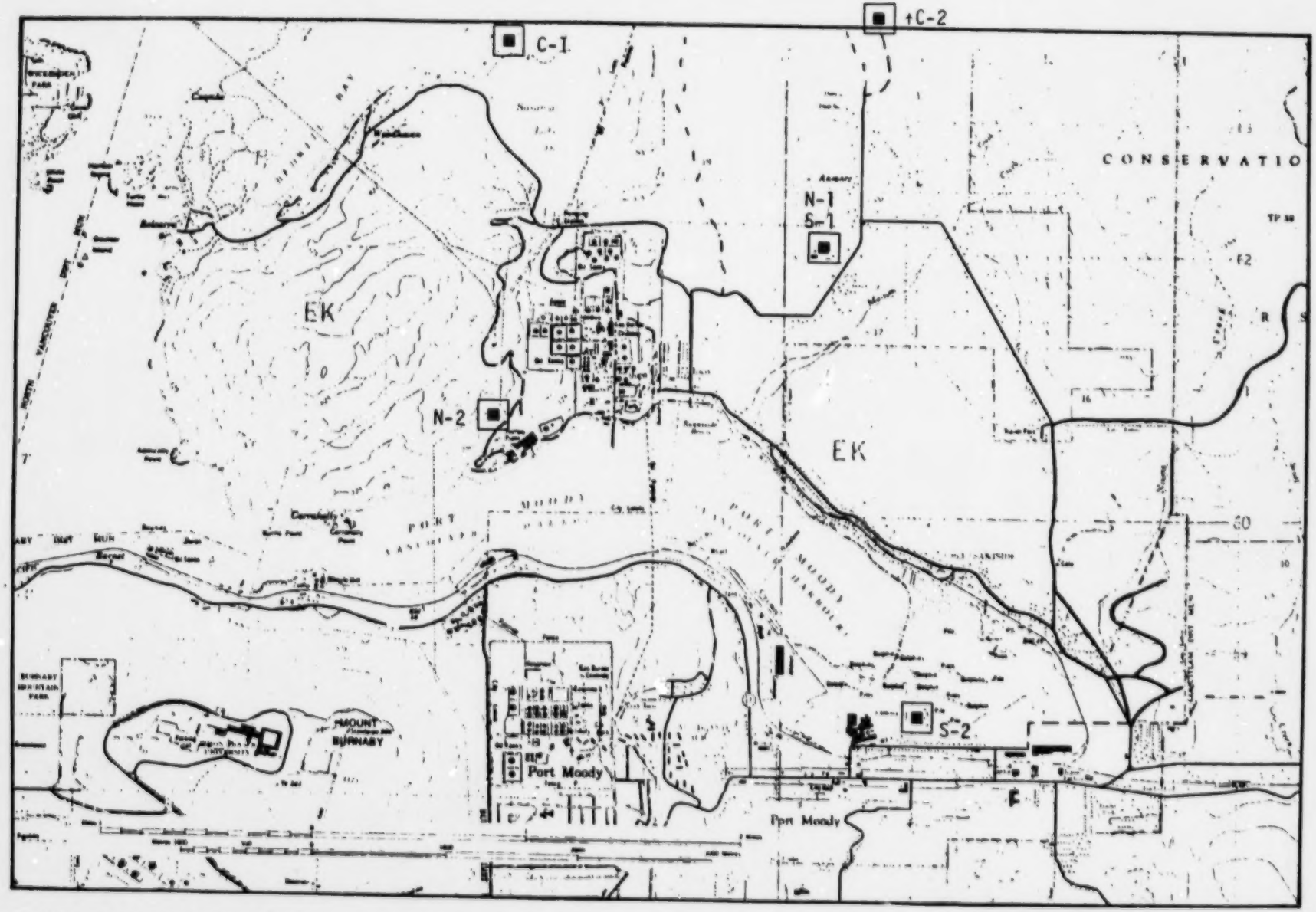


Figure 7. Map showing locations of proposed vegetation monitoring plots. N: indigenous, S: sensitive, C: control

these locations are at sites inspected in the field survey shown in Figure 6.

1. INDIGENOUS VEGETATION - permanent plots
   Plots (20 x 20 m) at N-1 (Anmore School) and N-2 (NW of BTGP) to include representative tree species, shrubs and ground covers, located so as to provide unimpeded access by ambient air.
   Corresponding control plots at C-1 (Figure 7) and C-2 (N end of Buntzen Lake).

2. SENSITIVE VEGETATION - permanent plots
   Plots (5 x 10 m) at S-1 (= N-1, Anmore School), and S-2 (Port Moody) to include sensitive grasses, located so as to provide unimpeded access by ambient air.
   Corresponding control plots at C-1 and C-2.
   Standardized plant cultivation systems should be installed at S-1 and C-1.

It is proposed that both indigenous and sensitive vegetation plots be located at Anmore School (N-1 and S-1), a sensitive vegetation plot in Port Moody (S-2) and an indigenous vegetation plot at N-3 (NW of BTGP). Control plots for both indigenous and sensitive vegetation should be located on the south-facing slope N of Sasamat Lake (C-1) and at the N end of Buntzen Lake.

Plots N-1/S-1 and S-2 will be useful because of their proximity to GVRD Stations T7 and T9, respectively.

On the basis of inspection of aerial photographs and topographic maps, the control plot locations (C-1, C-2) appear to be comparable to N-1 and N-2, but are less easily accessible.

The sensitive vegetation plots and the standardized cultivation systems should be planted (after clearing and cultivating as necessary) with the four perennial grass species: Dactylis glomerata cv Aberystwyth S37, Poa pratensis cv Monopoly, Lolium multiflorum cv Milano, and Phleum pratense cv Eskimo, using the named cultivars wherever possible (15).

All sites should be inspected at regular monthly intervals,

especially during spring and fall, in order to observe symptoms, if any, and any changes in species distribution. The plants grown on the plots of sensitive species, particularly those in the standardized cultivation systems, should be inspected and harvested at regular intervals in order to permit growth measurements and observations on phenology and development to be made.

No attempt has been made at this time to identify the precise locations of any of the sites. However, those containing plantings of sensitive species and the standardized cultivation systems will require protection from vandalism, and this requirement may dictate to some extent their location.

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APPENDIX A

The following observations were made at various sites inspected on September 19 and 20, 1981. The locations are shown on Figure 7 in the body of the report. Sites 1-7 were also inspected by B.C. Hydro personnel in March 1981 **(43)**. Photographs relevant to certain sites are in Appendix B.

Site 1: Burnaby Centennial Park (Plate 1)

No obvious symptoms of injury attributable to air pollutants on dominant indigenous trees on N-facing slope adjacent to park, or on variety of species planted in Park. Signs of leader die-back on Douglas fir probably attributable to winter injury. Premature chlorosis on maple and alder on N-facing foliage possibly attributable to N-exposure, although continuous fumigations with low levels of SO_2 and NO_2 might be contributing.

Site 2: B.C. Hydro Control Centre (Plate 2)

Some loss of second-year needles on mature Douglas fir and severe defoliation of mature hemlock probably attributable to land disturbance. No symptoms on other vegetation.

Site 3: Clearing S of Barnet Highway (Plate 3)

Mixed stand of hemlock, cedar, birch, alder, maple and cottonwood on N-facing slope. No obvious symptoms. Advanced chlorosis of bigleaf maple (Plate 4) probably attributable to fungal leaf-spot disease.

Site 4: Clearing S of Barnet Highway (Plate 5)

Mixed stand of hemlock, cedar, Douglas fir, cottonwood, maple, alder and birch. No obvious symptoms, but some apparent chlorosis of first-year hemlock needles on one tree - cause unknown.

Site 5: Slope N of BTGP Switchyard (Plate 6)

Abundant lichen and moss flora on exposed surfaces with no obvious signs of impaired growth. Depauperate growth of isolated Douglas fir, hemlock and cedar with some needle necrosis, premature needle shedding and apparent die-back on SE-facing branches. Confirmation of observations in **43**. No symptoms on *Spiraea menziesii* (hardhack), *Cytisus scoparius* (broom) or *Gaultheria shalon* (salal).

Sites 6 and 7: not inspected.

Site 8: B.C. Hydro Road to BTGP (Plate 7)
Some terminal die back of mature cedar. No symptoms on Douglas fir.

Site 9: B.C. Hydro Road to BTGP (Plate 8)
Abundant moss on scree slopes and boulders (Polytrichum spp.). Trees on slope show poor growth probably because of soil slippage.

Site 10: Anmore School (Plate 9)
No symptoms on dense stand of cottonwood N of GVRD monitoring trailer. Suggestion of chlorosis on S-facing branches of Douglas fir (Plate 10) but no obvious symptoms.

Site 11: Road to Buntzen Lake (Plate 11)
No signs of injury.

Site 12: East Road, S of Mossom Creek (Plate 12)
Mixed stand on SW-facing slope. No symptoms on hemlock or cedar. Suggestion of chlorosis on mature Douglas fir.

Site 13: East Road (Plate 13)
No symptoms on mixed stand of Douglas fir, hemlock, cedar, alder and birch.

Site 14: Intersection of Noon's Creek Drive and Blackstock Road (Plate 14)
No signs of injury.

Site 15: Slope SW of Jane Road (Plate 15)
No symptoms on cedar, hemlock, cottonwood; alder and maple with mottled foliage probably attributable to fungal disease.

Site 16: Gatensbury Road (Δ1031) (Plate 16)
Douglas fir with shedding of second-year needles. Maples chlorotic, but no symptoms noted on any ornamentals.

APPENDIX B

Plate 1. View towards NE from Burnaby Centennial Park (Site 1), overlooking BTGP, showing leader die-back of Douglas fir, premature senescence of alder.

Plate 2. B.C. Hydro Control Centre (Site 2). Severe defoliation of hemlock, some loss of 2nd-year needles of Douglas fir.

Plate 3. N-facing slope, Barnet Highway (Site 3). Mixed stand; some signs of premature chlorosis and necrosis on young leaves of bigleaf maple.

Plate 4. Close-up of bigleaf maple (Site 3).

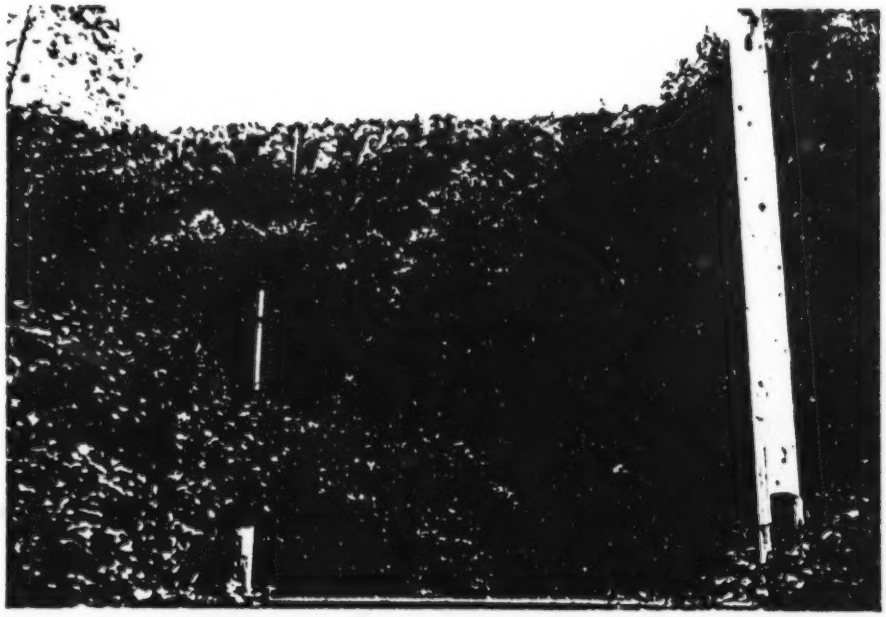

Plate 5. N-facing slope, Barnet Highway (Site 4). Mixed stand; some premature senescence of birch and maple, and chlorosis of first-year hemlock foliage.

Plate 6. Slope N of BTGP switchyard (Site 5). Douglas fir showing loss of needles on terminal growth.

Plate 7. B.C. Hydro road (Site 8). Terminal die-back of mature cedar.

Plate 8. B.C. Hydro road (Site 9). Thin crowns of hemlock, cedar and Douglas fir, probably due to unstable soil.

Plate 9. Cottonwood and mixed stand N of Anmore School (Site 10). Suggestion of chlorosis on Douglas fir.

Plate 10. Douglas fir W of Anmore School (Site 10), with chlorosis on S-facing branches and leader die-back.

Plate 11. B.C. road to Buntzen Lake (Site 11). Healthy mixed stand.

Plate 12. East Road, S of Mossom Creek (Site 12). Chlorosis and bronzing of Douglas fir foliage.

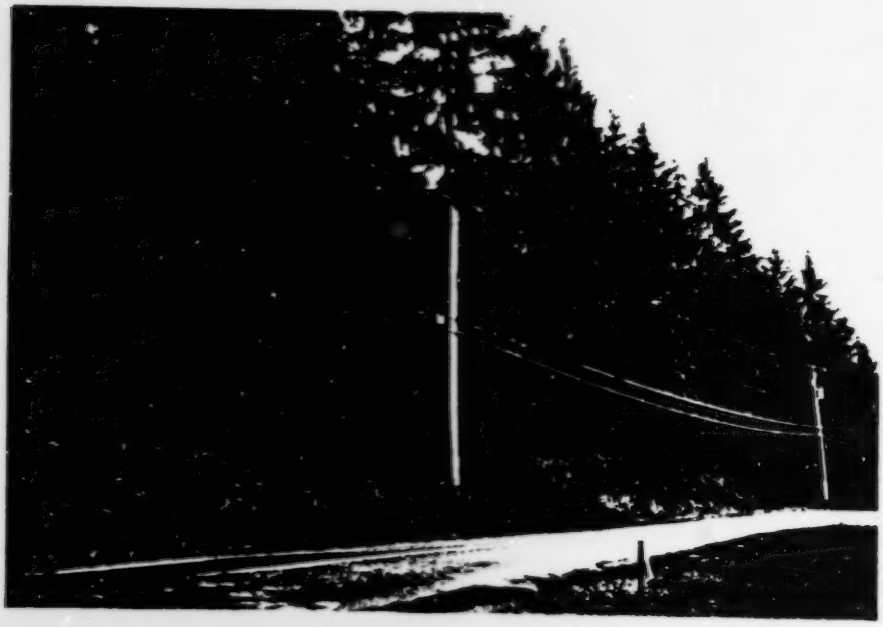

Plate 13. East Road (Site 13). Healthy mixed stand.

Plate 14. Noon's Creek Dr./ Blackstock Rd. (Site 14). Healthy mixed stand.

Plate 15. Slope SW of Jane Road (Site 15). Healthy mixed stand of cedar, hemlock and cottonwood; some chlorotic mottling on maple and alder.

Plate 16. Gatensbury Road, towards E (Site 16). Extensive loss of needles of disturbed Douglas fir; terminal chlorosis of maple.

POOR

QUALITY

ORIGINAL